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ORIGINAL ARTICLE

Evaluation of Capacity and Level of Service for Heterogeneous Traffic of Urban Multi-Lane Highways

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ABSTRACT – This study aimed to evaluate the capacity and level of service of urban multi-lane highway where the traffic composition is not uniform. Capacity is the greatest sustainable hourly flow rate, and the level of service is a performance measure used for assessing the quality of road service. In this study the last methodology of HCM2016 was used. Data collection was done on four different segments chosen to be suitable with the highway capacity manual conditions. Traffic volumes have been collected using two different techniques; moving car method and the stationary method. All the required geometric parameters have also been measured. The peak hour factor has been found for all the segments. The spot speed was used to check the speed limit (mounted speed) and to find free flow speed. At the end, the level of service and capacity for the segments were found. The level of services of most of the segments is between C and D. The base capacity of the segments is between 1850 to 1900 pc/h/ln.

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INTRODUCTION

Over the past decade, the use of motorized vehicles has significantly increased with the rapid growth of urbanization in Iraq. The robust increase in population has presented a challenge for the development of modern society which has turned into a major concern in metropolitan cities in developing countries like Iraq. At present, the world population crosses seven billion and the population residing in urban areas accounts for nearly half of this figure which is expected to rise up to 60 % over the world's entire population by the end of 2025 [1]. Iraqi cities are well connected with urban roads and rural roads everywhere; however, there exists poor transportation networks connectivity with negligible intra and intercity facilities. Hence, traffic flow in heterogeneous conditions is highly complex and it is difficult to predict the flow behavior on urban roads. Driver's comfort, convenience, traffic volume, lane width, grade type, geometric design, travel delay and safety are the major concerns on Iraqi urban roads which are to be taken into account. Monitoring traffic volume and level of service which represents quality transport has become indispensable [2,3]. Capacity gives a quantitative measure of traffic, whereas a qualitative measure is Level of Service (LOS). The capacity of a road may remain constant, but the actual flow rate will vary depending on the day of the week and time of day. LOS and Capacity for a multi-lane highway segment are usually determined by combining the macroscopic parameters; traffic volume, density, average speed, peak hour factor, and other minor parameters [4]. LOS is used to qualitatively define the operating conditions for a roadway depending on several factors that have been previously mentioned. According to Highway Capacity Manual (HCM), multi-lane highways are those that have two or more lanes in each direction of travel. The LOS of this roadway facility is designated with a letter A to F, with A representing the best operating condition and F the worst condition. HCM2016 uses density in terms of passenger cars per mile per lane as the primary measure for LOS on multi-lane highways [5].

The fundamental diagram approach can be used to estimate capacity for multi-lane highway segments. In practice, the approach has been found to be a good way for predicting capacity. The capacity of segments is graphically determined by deriving the function of the flow-density relationship. The maximum value obtained from the curve is produced by setting the first derivative to zero, which indicates the observed capacity of the segments studied [6]. According to HCM2016, the base capacity is claimed to be a function of the Free Flow Speed (FFS) seen across the particular segment of road when the basic conditions are met. Base conditions for achieving full capacity of a multi-lane highway segment include good weather, adequate visibility, no incidents or accidents, no work zone activities, and no pavement deterioration severe enough to interfere with operations. The term "basic conditions" implies that certain conditions exist [5].

For multi-lane highways, the base capacity values stated in the HCM2016 range from 2300-1900 pc/h/ln, depending on the FFS. As a result, it is clear that base capacity is a variable that varies depending on locality. Considering the studies done to build base capacity, it's value changes with different roadway and traffic factors. As a result, the empirical capacity values of non-standard locations will deviate from the base value. Capacity reduction elements in the HCM2016 guideline include lane width, median type, free flow speed, access point density, and lateral clearance. The impact of these elements has also been demonstrated in independent research articles. The influence of lane width on capacity [7], The impact of the median type on FFS and thus capacity [8], the effect of FFS on capacity [9], the effect of access point,

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bus stops, curbside parking, pedestrian activity [10,11] and the effect of lateral clearance were observed in the published literature. Aside from these factors, vehicle composition was found to have a substantial impact on capacity [12].

The main objective of this study is to evaluate the LOS and capacity for an urban multi-lane highway under heterogeneous traffic conditions. It is performed using real data collected at four different segments on Malik Mahmood Ring Road in Sulaymaniyah city. We will also investigate the capacity of multi-lane highways. The detailed information on the various parameters is also presented. The FFS is a key parameter that is widely used for analyzing the LOS and capacity of various types of highway facilities.

LITERATURE REVIEW

Anamika et al. [13] investigated the capacity of inter-urban multi-lane highways in India, estimating that the capacity per lane on a four-lane highway is 2250 pc/h/ln. The capacity value was calculated assuming that capacity occurs at half the free flow speed. Sathishkumar et al. [14] studied base capacity under ideal road conditions, and estimated the base capacity of urban Indian 4-lane roadways (3.5m lane width, and no road side friction). The vehicle composition was 64.8 percent cars, 3.7 percent heavy vehicles, and the remainder motorcycles and three-wheelers. The projected lane capacity was 1570 pc/h/ln. The operational speed, defined as the 85th percentile value of passenger car free flow speed, was assessed to be 64 kmph.

Biswas et al. [15] conducted field investigations in Kolkata metropolis city, utilizing a video graphic approach to observe and collect traffic flow characteristics on urban arterials. The obtained data, such as mean speed, standard deviation, and coefficient of variation, have been paired with standard values. To ensure that the simulated distribution curves were compatible, the Kolmogorov-Simonov (K-S) test was used. PSR was divided into a number of subgroups using a clustering approach. The analysis concluded that the metropolitan's study operational circumstances on roads fell within LOS F, indicating the need for quick LOS improvement.

Chatterjee et al. [16] studied the level of service for multi-lane highways in India using platoon variables such as follower rate, follower density, percentage follower, and platoon rate. Traffic flow is classified using the K-means clustering technique into three categories: free flow, stable flow, and constraint flow. Stream variables such as flow rate, density, and v/c ratio were investigated in all six segments of the study, with time headway being used as a parameter to determine platoon criterion. The relationship between level of service and capacity is well addressed by Raji and Jagannatham in their paper. The concept of level of service and its classification from A to F has been explained with graphical representation. Some of the inputs used included changes in LOS, safety, road traffic influences, heterogeneous traffic conditions, and road user [17].

Mohammed Ali et al. [18] conducted video graphic surveys on a 60-M ring-road in Erbil, Iraq, to collect data on traffic volume and vehicle spot speed. The results show that the average vehicle speed is about 19 km/h, which is less than the designed speed of 60 km/h, resulting in LOS for that particular road segment being in the 'F' category. Peak hour factor is 0.97 which exceeds the range of typical values that are given for urban areas. Mohammed and Abdulkhalik [19] estimated the capacity of six-lane multi-lane highways in Kirkuk city, which included composite traffic, at 1607 pc/h/ln. In the study, this value was chosen to represent the existing prevailing conditions.

RESEARCH METHODOLOGY

In this research the following methods have been used to find traffic flow, density, mean speed, spot speed, free flow speed, capacity and level of service:

The Moving Vehicle Method (MVM) is a method developed by Wardrop and Charlesworth in 1954 for measuring traffic flow, speed and travel time across a roadway. It uses Equations 1, 2 and 3 respectively.

$$V_w = \frac{M_a + M_o - M_p}{T_w + T_a} * 60 \tag{1}$$

$$S_w = \frac{L}{\bar{T}_w} * 60 \tag{2}$$

$$\bar{T}_w = T_w - \left(\frac{(M_o - M_p) * 60}{V_w}\right) \tag{3}$$

Where M_a: The number of vehicles met (opposing flow), M_o: Total vehicles overtaking the test car, M_p: Total Vehicles that passed by the test car, T_a: Travel time in minutes while traveling east, and, T_w: Travel time in minutes while traveling west, $\bar{T}_w$: Average travel time in the westbound direction, and S_w: Space mean speed in the westbound direction.

The segment facility's level of service is a qualitative indicator. It is a popular measure of effectiveness (MOE'S) alternative for evaluating traffic congestion that could emerge at any segment or intersegment approach. The letter grading system from LOS A to LOS F is used to represent a range of traffic quality. When the LOS changes from A to F, the quality of the traffic stream degrades. For uninterrupted multi-lane highways, LOS is calculated using traffic density estimates rather than a relatively constant speed over a wide range of flow rates. Traffic density can be used to measure the influence of vehicle interaction and closeness in the traffic stream using Equation 4 from chapter 12-HCM2016. As performance essential traffic-flow characteristics, three traffic parameters are utilized to describe LOS for multi-lane highways.

$$D = \frac{V_p}{S} \tag{4}$$

Where v_P= demand flow rate under equivalent base (pc/h/ln), S: mean speed (mi/h)

Free Flow Speed refers to the average speed of vehicles traveling on road segments free of intersection impacts (uninterrupted flow) and assessed in light to moderate traffic density situations. FFS has measured traffic flow rates up to 1400 pc/h/ln on multi-lane roadways (HCM2016). It is a significant variable that is combined with adjusted flow rate to determine the roadway's LOS. FFS is influenced by the road's geometry and environmental conditions. For assessing the FFS of a multi-lane highway segment, the HCM2016 approach provides an indirect method using Equation 5. The proposed method is based on applying equations from chapter 12-HCM 2016.

$$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A \tag{5}$$

Where *FFS*: free-flow speed of the multi-lane highway (km/h), *BFFS*: base FFS for the multi-lane highway (km/h), f_{LW}: adjustment for lane width (km/h), f_{TLC}: adjustment for total lateral clearance (km/h), f_M: adjustment for median type (km/h), and f_A: adjustment for access point density (km/h).

For each stretch tested, the BFFS was calculated by taking the posted speed plus 8 km/h (5 mi/h) for speed limits of 80 km/h and above, and plus 11 km/h for speed limits of less than 80 km/h (HCM- 2016). For computing LOS on multi-lane highways with required geometric data and diverse traffic conditions, the same methodology of HCM 2016 will be adopted.

To convert traffic volume to demand flow rate using Equation 6 from chapter 12-HCM2016.

$$v_P = \frac{V}{PHF * N * f_{HV}} \tag{6}$$

Where v_P= demand flow rate under equivalent base (pc/h/ln), *V*= demand volume under prevailing conditions (veh/h), *PHF*= peak hour factor, *N*= number of lanes in analysis direction (In), and f_{HV}= adjustment factor for presence of heavy vehicles.

Heavy vehicle adjustment factor is found using Equation 7 from chapter 12-HCM2016.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \tag{7}$$

Where f_{HV}= heavy vehicle adjustment factor (decimal), P_T= proportion of SUTs and TTs in traffic stream, and E_T= passenger car equivalent of one heavy vehicle.

For capacity computations, the same procedure of HCM2016 will be used to estimate base capacity values at each location using Equation 8.

$$base\ capacity = 1900 + 20 * (FFS - 45) \tag{8}$$

STUDY AREA AND DATA COLLECTION

Sulaymaniyah city was chosen as the study area for this research. Sulaymaniyah governorate is located in the Kurdistan region of Iraq (35° 33' 0" N, 45° 26' 0" E) at about 185 km from the southeast of the capital of Erbil. Sulaymaniyah city is characterized by a high traffic density due to the presence of commercial activities, tourism and government offices. Eight segments of six-lane divided urban roads in Sulaymaniyah were selected for data collection (see Figure 1).

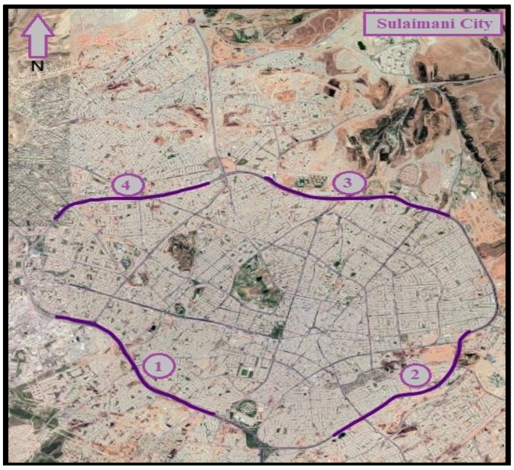

Figure 1. Study Area with Selected Segments of Sulaymaniyah City.

Geometric data for the segments were collected using field measurements, as shown in Table 1. The length of each segment studied was more than the minimum requirements by the Highway Capacity Manual (HCM2016) methodology that have been specified to be 762 m (2500 ft.) and located more than 400 m (0.25 mile) away from the intersections.

Table 1. Geometric Data for Road Segments

No.	Segment Name	Direction	Segment Length (m)	Lane Width(ft) & (m)	No. of Lanes per Direction	Median Type	Total Lateral Clearance (ft)	Access Point Density (per mile)
1	West Malik M.R.R.	EB	2415	11 (3.35m)	3	Divided	11.33	2.7
2	West Malik M.R.R.	WB	2415	11.30 (3.40m)	3	Divided	11	2.7
3	East Malik M.R.R.	EB	2800	11 (3.30m)	3	Divided	10.16	5.75
4	East Malik M.R.R.	WB	2800	11 (3.30m)	3	Divided	11	4.6
5	North Malik M.R.R.	EB	2640	11.33 (3.40m)	3	Divided	10.33	5.5
6	North Malik M.R.R.	WB	2640	11 (3.30m)	3	Divided	10.33	4.25
7	Altun Malik M.R.R.	EB	1600	11.16 (3.35m)	3	Divided	11	6
8	Altun Malik M.R.R.	WB	1600	11 (3.30m)	3	Divided	11	7

TRAFFIC DATA COLLECTION

Traffic data was collected for each segment during working days using video-recording technology. This approach allowed several occurrences to be observed at the same time. Data was collected utilizing a digital dash camera with a built-in GPS receiver that tracks location and speed by the second, as well as video recording time. The camera was connected to the front of the test car's windscreen and was controlled by a vehicle cigar plug. For improved accuracy, the required traffic parameters were manually retrieved from those videos through replaying them. For each segment, thirty runs were performed in order to confirm that the data obtained was most reliable. Mortimer, in 1957, demonstrated that six test runs are sufficient and accurate for an unbiased estimation of the measuring variables in each traffic direction. Table 2 shows the computation sheet of moving vehicle method for the West Malik Mahmud ring road form east to west.

Table 2. Sheet Results of Moving Car Technique

Segment Name	West Malik Mahmud Ring Road
Direction of segment	E - W
Length of segment	2415 m
Test run number	1
Date	30-3-2022
Time	8:00 - 9:00 am

Table 2. Sheet Results of Moving Car Technique (cont.)

Traffic condition	Peak Hour	
weather	Good weather	
Input Data to Moving Car Technique		
Ma	410	Vehicles
Mo	5	Vehicles
Mp	6	Vehicles
Ta	2.7	Minutes
Tw	3.48	Minutes
Obtained Results		
Travel Time	3.5	Minutes
Traffic Volume	3971	Vehicles
Average Speed	41	km/h
Density	96	Veh/km

PEAK HOUR FACTOR (PHF) AND SPEED LIMIT DETERMINATION

Based on HCM2016 methodology, the stationary observer approach was used to find the PHF within the peak-hour. Any 15-minute period could be used as the tests were conducted during working hours from 7:00 A.M. to 5:00 P.M. The highest traffic volume acquired from test runs was used to identify the peak hour volume. As a result, the peak hour was found for each segment in order to undertake a stationary observer method study. Figure 2 shows the PHF and hourly traffic volume variation on the West Malik M.R.R. segment for both directions, the blue one is for the west, and the other is for the east direction. The values of PHF for entire segments varied from 0.92 to 0.95 which are normal values for multi-lane urban highways according to HCM2016.

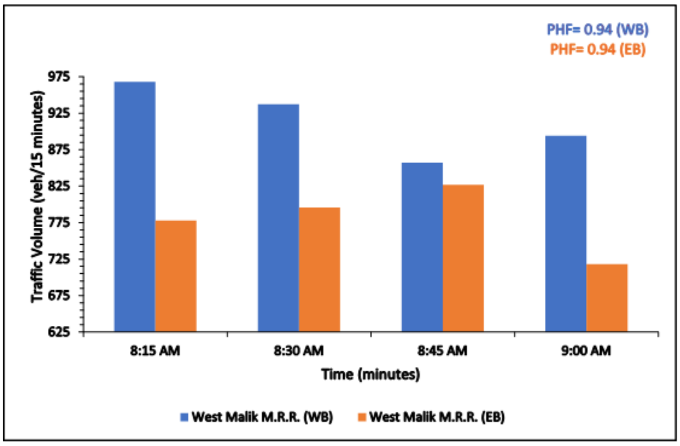

Figure 2. A 15-Minutes PHF and Traffic Volume Variation on West Malik M.R.R. Segment.

The HCM method was used to find the traffic flow parameters and PHF, thereby one can reach conclusions to determine the LOS and capacity of roads using two different techniques; moving vehicle and stationary technique see Table 3. Data, for each segment, were collected from 8:00 am to 5:00 pm. The peak hour volume was found. It can be noticed that traffic volume is high at all segments except the East Malik Mahmud Ring Road (WB). Traffic volume at (EB) of the same segment is high due to the presence of public and private hospitals and several other institutions. The PHF was used to predict demand flow rates. The flow rates were calculated by multiplying the 15-minute volumes by four. The findings of the stationary approach are shown in Tables 3.

Table 3. Traffic volume (MVM), PHF, Traffic Volume, and Flow Rate of the Segments Using Stationary Method.

No.	Segment Name	Direction	Peak Hour	Traffic Volume (veh/h) (MVM)	Traffic Volume (veh/h)	Flow Rate (veh/h)	PHF	Proportion of Heavy Vehicle (P_T)	f_{HV}
1	West Malik M.R.R.	EB	8:00-9:00 am	3444	3119	3308	0.94	6.28%	0.94
2	West Malik M.R.R.	WB	8:00-9:00 am	3971	3656	3872	0.94	5.17%	0.95
3	East Malik M.R.R.	EB	2:00-3:00 pm	2720	2601	2796	0.93	2.65%	0.97

Table 3. Traffic volume (MVM), PHF, Traffic Volume, and Flow Rate of the Segments Using Stationary Method (cont.)

No.	Segment Name	Direction	Peak Hour	Traffic Volume (veh/h) (MVM)	Traffic Volume (veh/h)	Flow Rate (veh/h)	PHF	Proportion of Heavy Vehicle (P_T)	f_{HV}
4	East Malik M.R.R.	WB	2:00-3:00 pm	1809	1631	1766	0.92	3.98%	0.96
5	North Malik M.R.R.	EB	4:00-5:00 pm	3252	3153	3324	0.95	1.90%	0.98
6	North Malik M.R.R.	WB	4:00-5:00 pm	3511	3572	3804	0.94	2.30%	0.98
7	Altun Malik M.R.R.	EB	1:00-2:00 pm	3283	2955	3100	0.95	1.96%	0.98
8	Altun Malik M.R.R.	WB	1:00-2:00 pm	3088	2788	2944	0.95	2.37%	0.98

The percentage of heavy vehicle, for each segment, does not reach 3% except for the direction numbers 1, 2 and 4, see Table 3. The P_T of the west Malik M.R.R. segment (EB) and (WB) exceeds 5%. The reason is due to the strategic location of these directions which are used as a bypass by the road users of different cities and large regions in Kurdistan Region. Spot speed studies were done to identify the speed limits at each segment, it was utilized to determine the base FFSs. Figure 3 depicts the speed limit of all the studied segments. All of the investigated segments have a posted speed limit of 60 km/h. However, after conducting a spot speed study, the actual speed limit was obtained by measuring the eighty fifth percentile speed for each segment. It was found that the actual speed limit of all segments was more than 60 km/h. The speed limits started at 65.55 km/h, up to a maximum of 70.25 km/h, see Figure 3.

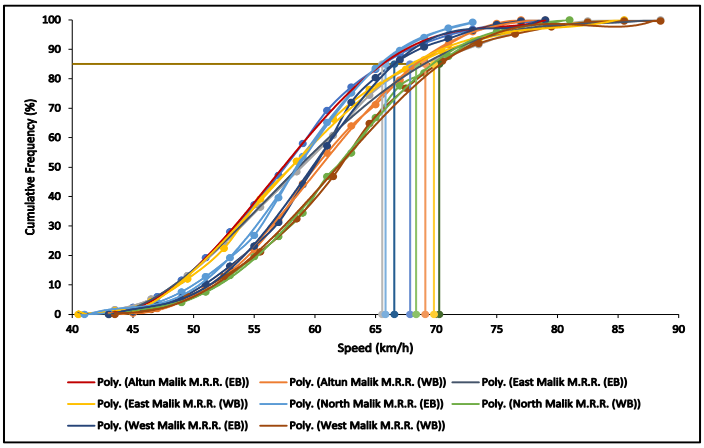

Figure 3. Speed Limit Study for Investigated Segments.

LEVEL OF SERVICE COMPUTATION

The parameters of the geometric characteristics of the segments are given in Table 1. The Free Flow Speeds at each location were calculated using Equation 5. The FFSs for the studied segments are shown in Table 4.

Table 4. FFSs Computation for the Sections.

No.	Segment Name	Direction	BFFS (mi/h)	f_{LW}	f_{TLC}	f_M	f_A	FFSs (mi/h)
1	West Malik M.R.R.	EB	46.36	1.9	0.13	0	0.75	43.58
2	West Malik M.R.R.	WB	48.66	1.33	0.2	0	0.75	46.38
3	East Malik M.R.R.	EB	47.17	1.90	0.36	0	1.5	43.40
4	East Malik M.R.R.	WB	47.95	1.90	0.2	0	1.25	44.60
5	North Malik M.R.R.	EB	45.74	1.27	0.33	0	1.5	42.63
6	North Malik M.R.R.	WB	48.40	1.90	0.33	0	1	45.17
7	Altun Malik M.R.R.	EB	45.91	1.69	0.2	0	1.5	42.52
8	Altun Malik M.R.R.	WB	47.78	1.90	0.2	0	1.75	43.93

Apart from BFFS, there are many other factors that affect FFS, including road geometry parameters; such as the lane width. In this study, the lane width was less than the standard value which has a significant impact on reducing the value of FFS. Another factor that has a significant impact on FFS is the number of access points. Peak hourly volume has been calculated using stationary methods. It has been converted to flow rate (vp) using Equation 6, see Table 5.

In order to find LOS, two key parameters are required; the first parameter is FFS, which has already been found, and the second parameter is the flow rate (pc/h/ln), see Table 5. Heavy vehicle adjustment factor was found using Equation 7. It was found according to HCM2016, see Table 5. The results of density (using equation 4), level of service and capacity are shown in Table 5.

After finding the fundamental parameters of speed, flow rate, and density using Equation 4, 5 and 6, the LOS of all segments according to the criteria mentioned in HCM2016 were found. LOS for both segments of West Malik M.R.R. and North Malik M.R.R. is D. This level confirms that there is excess load on the two sections therefore the users cannot drive at the desired speed. The other segments are at a grade C, except East Malik M.R.R. in the west direction which is B due to low traffic volume. The estimated base capacities were found using Equation 8. The results are shown in Table 5.

Table 5. Level of Service and Capacity Computation for the Segments.

No.	Segment Name	Direction	Flow Rate (pc/h/ln)	FFS (mi/h)	Density (pc/mi/ln)	LOS	Capacity (pc/h/ln)
1	West Malik M.R.R.	EB	1176	43.58	27	D	1872
2	West Malik M.R.R.	WB	1364	46.38	29	D	1928
3	East Malik M.R.R.	EB	957	43.40	22	C	1868
4	East Malik M.R.R.	WB	615	44.60	14	B	1892
5	North Malik M.R.R.	EB	1127	42.63	26	D	1853
6	North Malik M.R.R.	WB	1296	45.17	29	D	1903
7	Altun Malik M.R.R.	EB	1058	42.52	25	C	1850
8	Altun Malik M.R.R.	WB	1002	43.93	23	C	1879

CONCLUSION

According to different versions of HCM, measuring capacity and LOS for the purpose of studying and evaluating multi-lane roads have changed year after year based on research, although the changes are not dominant. The following points have been concluded:

1) Multi-lane highway segments can be characterized by several performance measures: density in passenger cars per mile per lane, space mean speed in miles per hour, and the ratio of demand flow rate to capacity *(v/c)*.
2) Estimation of level of service depends on free flow speed and average travel speed. Travel time can be converted to travel speed by dividing the travelled distance by the travel time.
3) FFS in the study exceeded 42.5 mi/h, therefore all the investigated segments had the characteristics of a multi-lane highway.
4) With an increase in the proportion of heavy vehicle in traffic streams, the traffic operations, and hence the LOS, will be adversely affected.
5) Traffic volume data collection using the moving car method is as efficient as the stationary method.

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REFERENCES

[1] R. Babit, V. Sharma, and A.K. Duggal, (2016). "Level of service concept in urban roads," *Int. J. Eng. Sci. Invention Res. Dev.*, vol. 3, no. 1, p. 44-48.

[2] Republic of Iraq, Ministry of Construction, Housing, Municipalities, and Public Works.

[3] R. Al-Daini, N. Danilina, and H.A. Alaraza, (2021). "Developing a theoretical model to improve the road network a historical city in Iraq," In *E3S Web of Conferences*, vol. 263, p. 05007, EDP Sciences.

[4] P.G. Kumar, S.R. Samal, L. Prasanthi, V. Bhavitha, and J.M. Devi, (2020, December). "Level of Service of Urban and Rural Roads-A Case study in Bhimavaram," In *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1006, no. 1, p. 012018). IOP Publishing.

[5] Manual, H. C. (2016). HCM2016. Transportation Research Board, National Research Council.

[6] M.M. Minderhoud, H. Botma, and P.H. Bovy, (1997), "Assessment of roadway capacity estimation methods," *Transp. Res. Rec.*, vol. 1572, no. 1, p. 59-67.

[7] S. Chandra, and U. Kumar, (2003), “Effect of lane width on capacity under mixed traffic conditions in India,” *J. Transp. Eng.*, vol. 129, no. 2, p. 155-160.

[8] R. Moses, and E. Mtoi, (2013). Evaluation of free flow speeds on interrupted flow facilities (No. BDK83 977-18). Florida. Dept. of Transportation.

[9] S. Sathishkumar, A. Rao, and S. Velmurugan, (2016). Base Capacity Estimation of Four Lane Divided Urban Carriageways under Mixed Traffic Conditions. 12th transport planning and implementation methodologies for developing countries. Bombay.

[10] S. Wijayaratna, (2015, October), “Impacts of on-street parking on road capacity,” In Australasian Transport Research Forum (pp. 1-15).

[11] S. Salini, S. George, and R. Ashalatha, (2016), “Effect of side frictions on traffic characteristics of urban arterials,” *Transp. Res. Proc.*, vol. 17, 636-643.

[12] S. Chandra, A. Mehar, and S. Velmurugan, (2016), “Effect of traffic composition on capacity of multilane highways,” *KSCE J. Civ. Eng.*, vol. 20, no. 5, p. 2033-2040.

[13] Y. Anamika, A. Ashutosh, and S. Velmurugan, (2014), “Roadway Capacity Estimation for Multi-Lane Inter-Urban Highways in India,” In Colloquium on Transportation Systems Engineering and Management. Calicut.

[14] S. Sathishkumar, A. Rao, S. Velmurugan, (2016), “Base Capacity Estimation of Four Lane Divided Urban Carriageways under Mixed Traffic Conditions,” 12th transport planning and implementation methodologies for developing countries.

[15] S. Biswas, B. Singh, and A. Saha, (2016), “Assessment of level-of-service on urban arterials: a case study in Kolkata metropolis,” *International journal for traffic & transport engineering*, vol. 6, no. 3, p. 303-312.

[16] S. Chatterjee, D. Roy, S. Chakraborty, and S. K. Roy, (2017), “Level of service criteria on Indian multilane highways based on platoon characteristics,” *Parameters*, 21(22), 23.

[17] S. Raji, and A. Jagannathan, (2017), “Evolution and application of level of service concept–A literature study,” *Int. J. Inf. Futur. Res*, vol. 4, no. 11, p. 8450-8474.

[18] R.F. Mohammed Ali, I.A. Hasan, S.A. Mohammed, and D.B. Qadr, (2019). “Improving the Level of Service of a Portion of 60-M Ring-Road in Erbil City,” *Cihan Univ.-Erbil Sci. J.*, vol. 3, no. 1, p. 12-17.

[19] H.N. Mohammed, and Abdulkhalik M. Al-Taei, (2021), “Evaluation of Acceleration Noise Parameter as a Traffic Flow Performance Indicator for Multi-Lane Urban Highways,” *Al-Rafidain Engineering Journal* (AREJ) vol. 26, no. 1, June 2021, pp. 44-52.